Prospects for Photovoltaics in Sunny and Arid Regions: A Solar Grand Plan for Chile
Part I – Investigation of PV and Wind Penetration

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Chile: The Atacama Solar Resource

Atacama Desert ~105,000 km²

<table>
<thead>
<tr>
<th>Station</th>
<th>Horizontal (kWh/m²/yr)</th>
<th>Latitude Tilt (kWh/m²/yr)</th>
<th>1-Axis Tracking, 0° Tilt (kWh/m²/yr)</th>
<th>1-Axis Tracking, 20° Tilt (kWh/m²/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crucero (1-yr)</td>
<td>2522</td>
<td>3055</td>
<td>3705</td>
<td>3866</td>
</tr>
<tr>
<td>Carrera (10-yr)</td>
<td>2535</td>
<td>3161</td>
<td>3905</td>
<td>4062</td>
</tr>
</tbody>
</table>

Capacity: 4.6 GW
Load: 15.4 TWh

Capacity: 14.1 GW
Load: 47.8 TWh
Chile 2010 Electricity Consumption

- 17 million people
- GDP per capita $16,000
- LCOE 3-56 ¢/kWh

Electricity consumption by origin:
- Hydroelectricity 33%
- Natural gas 23%
- Coal 35%
- Oil 7%
- Wind 1%
- Biomass 1%

Electricity consumption by sector:
- Residential 16.3%
- Commercial 12.3%
- Industrial 23.9%
- Mining 34.9%

SIC Typical Daily Load

Source: www.pv-insider.com/chile

Source: Bloomberg 2011
Twenty-five LANDSAT 7 images from December-March of 2010-2013 from the Peruvian border through the Santiago Metropolitan Region were mosaicked together in ArcMap
PV Site Suitability Study

Best regions for deploying PV based on a Combination of Land Cover & Tilt, Insolation, Proximity to Roads & Substations
Solar Irradiation & Wind Speed Data

Hourly Horizontal Global Solar irradiation data were accessed from Chile’s Solar Explorer portal for two substations:
- Crucero (SING)
- Carrera (SIC)

Hourly Wind (ASOS) data, from Iowa State University web-site for:
- Arica,
- Iquique,
- Calama,
- Antofagasta
- Desierto

(SIC)
- Viña del Mar
- Concepción
- Futaleufú (SIC)
Global Horizontal Irradiation ($W/m^2$)

Mostly clear skies throughout the year on the Atacama Desert!
and Latitude Tilt Global Irradiation (W/m²)
and 1-axis Tracking axis Global Irradiation (W/m²)

One-axis systems were modeled after First Solar’s 5 kW tracker with rotational limits of ±45 degrees
and 1-axis Tracking axis at 20 degrees Global Irradiation (W/m²)

Best configuration is to have the rotational axis tilted towards the north while the tracker rotates east to west.

One-axis systems were modeled after First Solar’s 5 kW tracker with rotational limits of ±45 degrees.
Capacity and Grid Penetration
PV and Wind Separately at SING

Photovoltaics

5% Curtailment  15% Curtailment

<table>
<thead>
<tr>
<th></th>
<th>5% Curtailment</th>
<th>15% Curtailment</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Only-</td>
<td>Capacity-DC</td>
<td>Penetration (%)</td>
</tr>
<tr>
<td>Horizontal Plane</td>
<td>2.2</td>
<td>34</td>
</tr>
<tr>
<td>Degree Tilt</td>
<td>2.1</td>
<td>35</td>
</tr>
<tr>
<td>PV Only-</td>
<td>Capacity-DC</td>
<td>Penetration (%)</td>
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<tr>
<td>Horizontal Plane</td>
<td>2.7</td>
<td>36</td>
</tr>
<tr>
<td>Degree Tilt</td>
<td>2.5</td>
<td>38</td>
</tr>
</tbody>
</table>

Wind

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<tr>
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<tbody>
<tr>
<td>Wind Antofagasta</td>
<td>Capacity</td>
<td>Penetration (%)</td>
</tr>
<tr>
<td>Wind Arica</td>
<td>2.7</td>
<td>30</td>
</tr>
<tr>
<td>Wind Calama</td>
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<td>32</td>
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<tr>
<td>Wind Deslerto</td>
<td>2.0</td>
<td>38</td>
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<tr>
<td>Wind Jolique</td>
<td>2.8</td>
<td>26</td>
</tr>
<tr>
<td>Wind Antofagasta</td>
<td>Capacity</td>
<td>Penetration (%)</td>
</tr>
<tr>
<td>Wind Arica</td>
<td>4.0</td>
<td>40</td>
</tr>
<tr>
<td>Wind Calama</td>
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<td>39</td>
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<tr>
<td>Wind Deslerto</td>
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<td>29</td>
</tr>
<tr>
<td>Wind Jolique</td>
<td>2.6</td>
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</table>
Capacity and Grid Penetration
PV and Wind Together at SING

5% Curtailment

15% Curtailment
Capacity and Grid Penetration
PV and Wind Separately at SIC

Photovoltaics

5% Curtailment 15% Curtailment

Wind

5% Curtailment 15% Curtailment
Capacity and Grid Penetration
PV and Wind Together at SIC

5% Curtailment

<table>
<thead>
<tr>
<th>Capacity (GW)</th>
<th>PV Only</th>
<th>Conception</th>
<th>Fataleufu</th>
<th>Vina del Mar</th>
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</thead>
<tbody>
<tr>
<td>5.5</td>
<td>4.9</td>
<td>2.2</td>
<td>3.7</td>
<td>3.3</td>
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</table>

15% Curtailment

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<tr>
<th>Capacity (GW)</th>
<th>PV Only</th>
<th>Conception</th>
<th>Fataleufu</th>
<th>Vina del Mar</th>
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<tbody>
<tr>
<td>6.6</td>
<td>5.1</td>
<td>5.0</td>
<td>5.6</td>
<td>6.0</td>
</tr>
</tbody>
</table>
Renewable Energy Status and Potential

- **Installed capacity of renewable energies**: 1236 [MW]
- **Potential of renewable energies**: between 212,000 MW and 291,000 MW

The first interconnection between SIC and SING is planned for 2017.
SERC-Chile Initiatives on the Integration of Renewables

Applications

AGC / SG

SCADA

Director Rodrigo Palma
• Universidad de Chile
• Universidad de Tarapacá
• Universidad de Antofagasta
• Universidad Técnica Federico Santa María
• Universidad Adolfo Ibáñez
• Universidad de Concepción
• Fundación Chile

45 faculty researchers, 6 postdoc, 30 graduate, 30 undergraduate
Conclusion - Southamerican 2033 Vision

200 GW ~ 4,800 km²
2 X (49x49 km²)
or
12 X (20x20 km²)

email: VMF5@columbia.edu
Typical hourly wind turbine outputs at SING
Typical hourly wind turbine outputs at SIC